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An Experimental Study on Recycle Concrete by using High Quality Recycled Coarse Aggregate

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Synopsis

This paper describes the properties of fresh and hardened concretes by using two kinds of high quality recycled coarse aggregates having a percentage of water absorption about 3%. These aggregates were made by demolished concretes of a school building constructed 70 years ago and of an apartment house constructed 44 years ago. Moreover, same experiments on a normal concrete using virgin aggregate were carried out in order to compare with the recycle concretes.

Synthesizing the experimental results, it is considered that high quality recycled coarse aggregates are able to apply for real structure under the condition of well mixed proportions.

KEYWORDS: recycle, recycle concrete, recycled coarse aggregate, tensile strength, tensile elasticity, drying shrinkage, neutralization

1. Introduction

In recent years a waste generated from structure demolition have been large amount in JAPAN. And some landfill sites will become to be a limited space in the not too distant future. Then the recycle system of debris concrete needs to be established as soon as possible.

This experimental study is a first step to investigate the possibility of application for real structure. High quality recycled coarse aggregates with a percentage of water absorption about 3% which were used in this experiment almost serve the Japanese Architectural Standard Specification JASS 5 Reinforced Concrete Work 2003[1]. The properties of fresh and hardened recycle concrete are mainly influenced by an amount of adhered cement mortar as well known[2)~4)]. Especially, influence to strength, elasticity and drying shrinkage is a comparative large and should be solved at the time of the application for real structure. Taking considerable notice to the relation between elasticity and drying shrinkage, this experiment was carried out.

2. Properties of high quality recycled aggregate

Two kinds of recycled coarse aggregates were used in this study. One is the crushed aggregate of university school building for 70 years after construction, which was made by passed through screw grinding machine four times after clashed by jaw crusher. And the other is the crushed aggregate of apartment building for 44 years after construction, which was crushed by jaw crusher and cone crusher. The former is written down RUG, the latter is

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written down RKG hereinafter. Crushed stone made in Aioi Hyogo was used as virgin aggregate for comparison. It is written down G hereinafter. Sea sand made in Karathu Saga was used as fine aggregate common to all concrete. Compressive strength of university school building and apartment building were examined just before the crush. Result of university school building was 13.3(N/mm^2). Result of apartment building was 27.9(N/mm^2).

2.1 Grading distribution

The examination was practiced according to JIS A 1102. Result of fine aggregate is shown in **Fig.1**. Results of coarse aggregate G, RUG and RKG are also shown in **Fig.2**. Fineness modulus of fine aggregate was 2.57, G was 6.80, RUG was 6.64, RKG was 6.26. Fine aggregate, G and RUG are within JIS distribution except for RKG. Particle shape of G was looked like sharp relatively. On the other hand, RUG was looked like round relatively. As shown in a Fig.2, there were very few aggregates 10mm or more in distribution of RKG and there were many fine grains as a whole in comparison with JIS distribution.

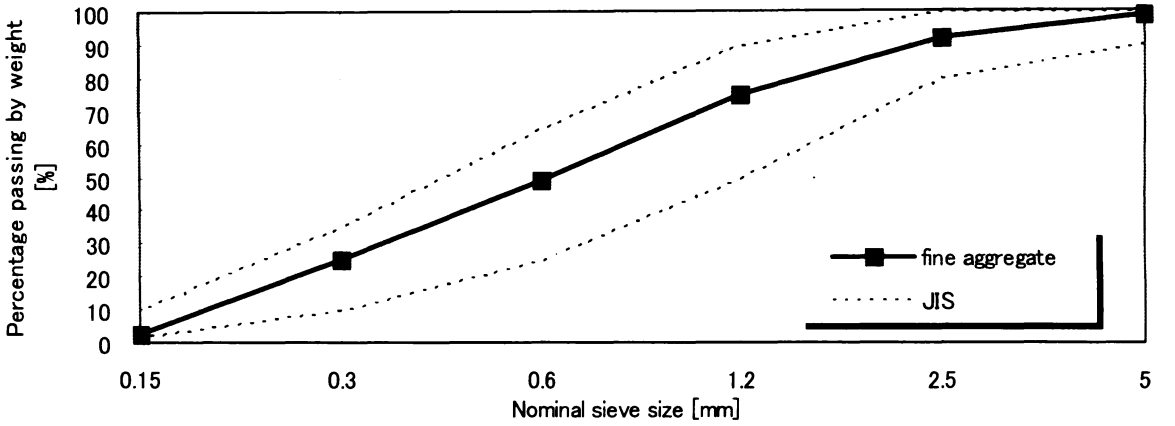

Fig.1 Grading distribution of fine aggregate

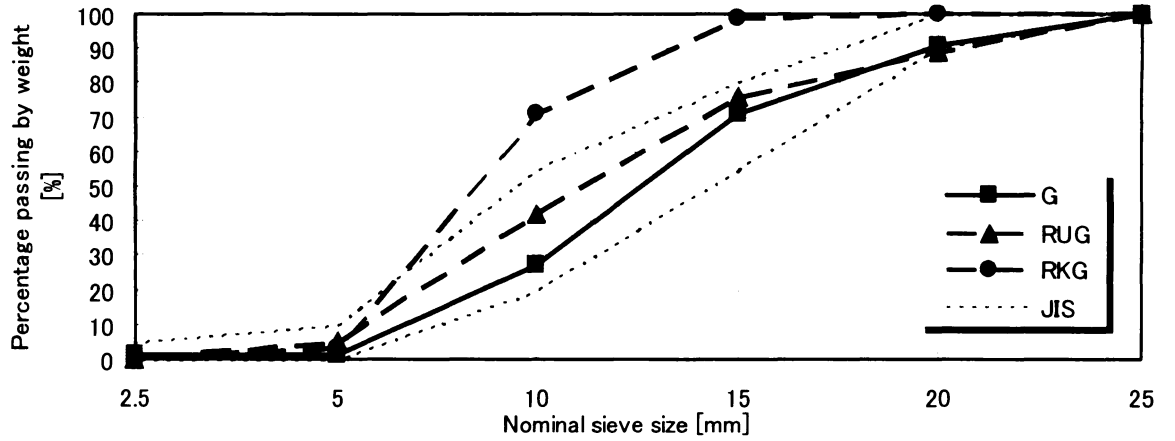

Fig.2 Grading distribution of coarse aggregate and recycled aggregate

2.2 Density and percentage of water absorption

The examination was practiced according to JIS A 1109 and 1110. Their results are shown in **Table 1**. Values of fine aggregate and G were very general in density and percentage of water absorption. RUG and RKG didn't satisfy JIS standard a little. However, since both (RUG and RKG) were not different widely to JIS standard, it can

be said that they are high quality aggregate equivalent to normal aggregate.

Table 1 Density and percentage of water absorption

	Fine aggregate	G	RUG	RKG
Surface-dry density [g/cm ^{3}]	2.55	2.61	2.53	2.56
Oven-dry density [g/cm ^{3}]	2.51	2.59	2.46	2.48
Percentage of water absorption[%]	1.69	1.07	3.21	3.02

2.3 Unit weight and percentage of solid volume

The examination was practiced according to JIS A 1104. Their results are shown in **Table 2**. All values satisfied JIS standard. Though density of RUG was smaller than one of G, value of RUG was larger than one of G in unit weight and percentage of solid volume. As this cause, it can be considered that the amount in examination container of RUG was filled up more than G because particle shape of RUG was looked like round in comparison with G.

Table 2 Unit weight and percentage of solid volume

	Fine aggregate	G	RUG	RKG
Unit weight [kg/L]	1.63	1.51	1.60	1.43
Percentage of solid volume [%]	65.1	58.4	65.1	57.8

2.4 Amount of adhered cement mortar

The mortar adhering to the surroundings of recycled aggregate was melted with 10% density hydrochloric acid, and the lost quantity was expressed in the percentage to the aggregate before the dissolution as Percentage of adhered cement mortar[5]. The examination result is shown in **Table 3**. From **Table1** and **Table3**, It can be said that the influence of adhered cement mortar is large because both density and percentage of water absorption after removal satisfy JIS standard.

Table 3 Percentage of adhered cement mortar, density and percentage of water absorption after removal

	Percentage of adhered cement mortar [%]	Oven-dry density after removal [g/m ^{3}]	Percentage of water absorption after removal[%]
RUG	18.6	2.55	1.73
RKG	19.4	2.54	1.96

3. Mix proportions

Mix proportions were practiced for the purpose of comparing the properties of concrete made by using recycled aggregate and virgin aggregate. It is shown as follows.

1) The water-cement ratios (W/C) were three levels (45, 55, and 65%).
2) The unit water content was constant in 185kg/m^3.
3) An objective slump and air content were 18±2.5cm and 4.5±1.5% respectively.
4) Bulk volume of coarse aggregate was constant 0.6 m^3/m^3.
5) The air-entraining and water-reducing agent (complex of the lignin sulfonic acid compound and the polyol), the air-entraining and high-range water-reducing agent (complex of the polycarboxylic acid ether system and the cross linked polymer), and the air-entraining supplementing agent (transformation rosin acid compound system in-ionic surface active agent) were used as chemical admixture.

Table 4 shows the value of going by the trial mixing method of JASS 5.

Table 4 Mix proportions

Symbol	W/C [%]	S/a [%]	W [kg/m^3]	C [kg/m^3]	S [kg/m^3]	Aggregate [kg/m^3]	Air content [%]	Chemical admixture 1[%]	Chemical admixture 2[%]
G-45	45	45.2	185	411	737	907	4.5	0.35	0.05
G-55	55	47.2	185	336	798	907	4.5	1	0.1
G-65	65	48.4	185	285	839	907	4.5	1	-
RUG-45	45	39.0	185	411	636	959	4.5	0.25	0.15
RUG-55	55	41.2	185	336	696	959	4.5	1	0.15
RUG-65	65	42.6	185	285	738	959	4.5	1	0.2
RKG-45	45	45.8	185	411	747	888	4.5	0.35	-
RKG-55	55	47.7	185	336	808	888	4.5	1.25	0.1
RKG-65	65	49.0	185	285	849	888	4.5	1	0.1

Note:Chemical admixture1 is air-entraining and water-reducing agent. Underline is air-entraining and high-range water-reducing agent. Chemical admixture2 is air-entraining supplement agent. All is × Cement (%).

4. Properties of fresh concrete

The examination was practiced according to JIS A 1101 and 1128. **Table 5** shows their results. The objective values in all concretes were able to be obtained, by using the air-entraining and high-range water-reducing agent only for the water-cement ratio 45%.

Table 5 Properties of fresh concrete

Symbol	Slump [cm]	Air content [%]	Unit weight [kg/L]
G-45	20.0	5.7	2.23
G-55	16.0	5.1	2.25
G-65	17.0	5.4	2.22
RUG-45	20.5	4.0	2.25
RUG-55	20.0	5.4	2.22
RUG-65	20.5	6.0	2.19
RKG-45	21.0	4.0	2.22
RKG-55	18.0	5.8	2.16
RKG-65	18.0	5.7	2.15

5. Properties of hardened concrete

The following experimental results on properties of hardened concrete were obtained.

5.1 28 days strength and elasticity

Specimen size of strength tests were 10φ×20 cm for compressive strength test and 15φ×15.5 cm for cleavage strength test. Both strains were measured by wire strain gauges.

Fig.3 shows the relation between compressive strength and cement-water ratio of each mix proportion. Compressive strength of recycled concrete has a smaller value as compared with the normal concrete. Those ratio are 78-88%(RUG) and 85-92%(RKG). But graph shows linear relation as to normal concrete. The relation between compressive strength and 28 days tensile strength is shown in **Fig.4**. The tensile strength of recycled concretes have values among 1/10-1/14 of compressive strength. This is the same tendency with normal concrete. Static modulus of compressive elasticity and strength are shown in **Fig.5**. And tensile elasticity and strength is also shown in **Fig.6**.

Concerning on the relation between strength and elasticity, both recycled and normal concretes show the linearity from these figure.

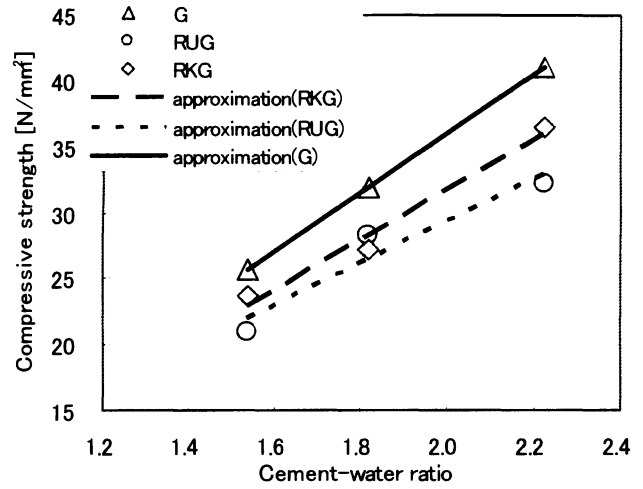

Fig.3 Cement-water ratio and compressive strength

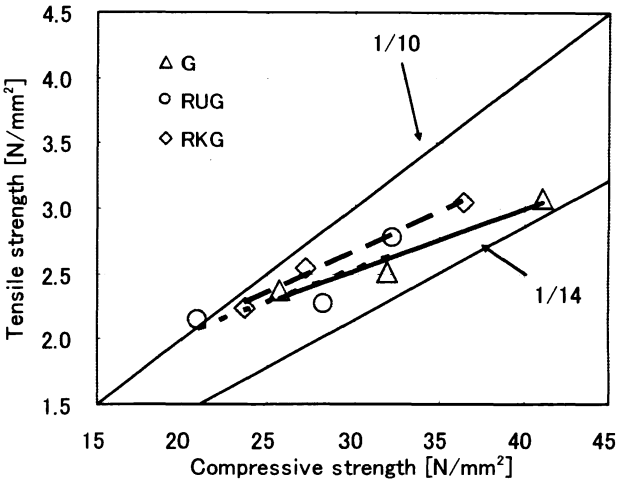

Fig.4 Compressive strength and tensile strength

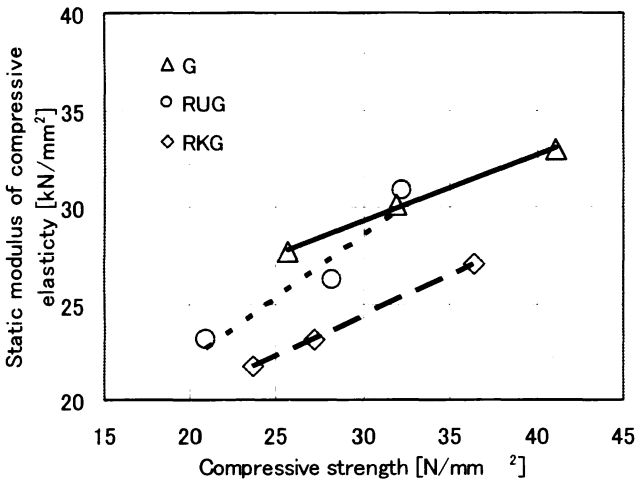

Fig.5 Compressive strength and elasticity

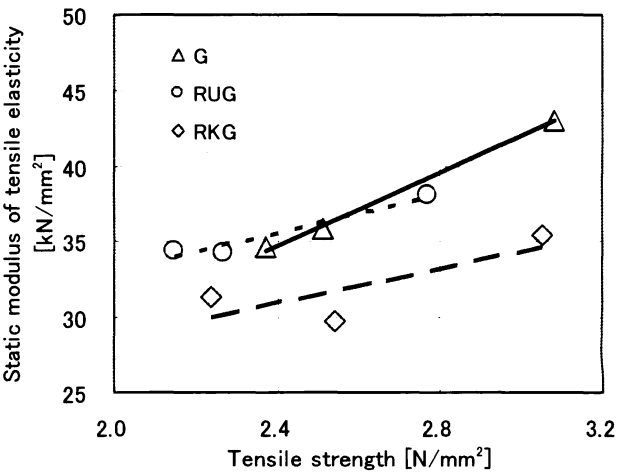

Fig.6 Tensile strength and elasticity

5.2 Drying shrinkage and decreasing weight

In this experiment 10cm×10cm×40cm rectangular specimen was used. After 1 day, it cures during 1 week in water and then it sets in a room with constant temperature and humidity (20℃, 60% RH).

Fig.7 shows the relation between drying shrinkage and duration till 26 weeks. Drying shrinkage ratio increases with its duration and the ratio does not have a constant value but still increases even after 26 weeks. Drying shrinkage of normal concrete has equal to or smaller value in comparison with recycled concrete. And water-cement ratio of concrete becomes to be larger, the value of drying shrinkage also has a tendency to increase. Drying shrinkage and decreasing weight at 2,4,6,8,13 and 26 weeks shows in **Fig.8**. These values are recognized good correspondence. The relations between drying shrinkage, 28 days compressive strength and modulus of compressive elasticity are shown in **Fig.9** and **Fig.10** respectively. From these figures, it is said as strength and modulus of elasticity increase, an amount of drying shrinkage decrease. But recycled concrete is not a evident on this point. It must be the influence of porous adhered cement mortar.

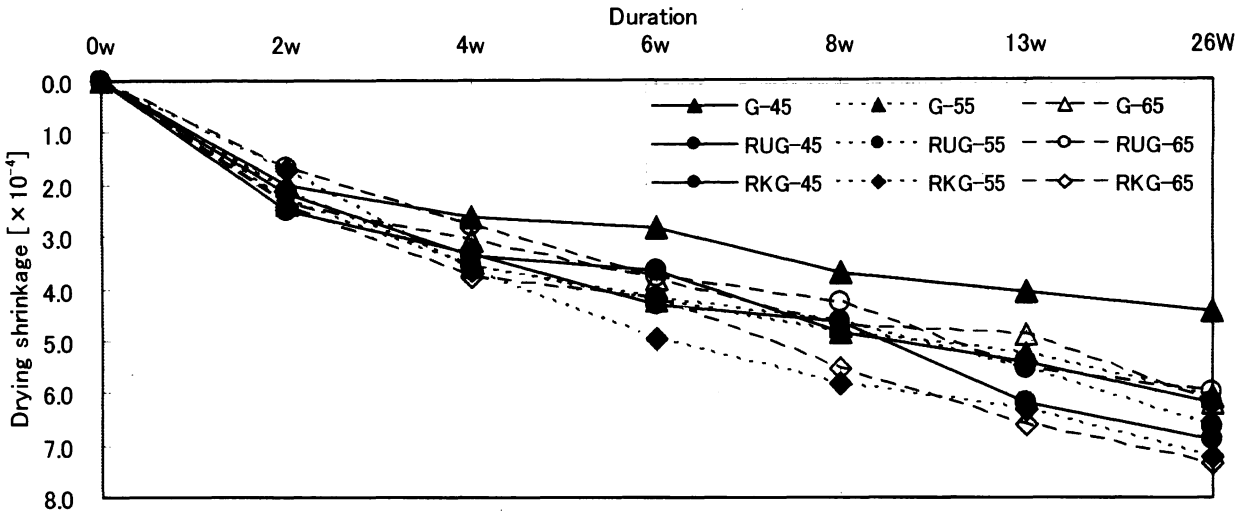

Fig.7 Drying shrinkage

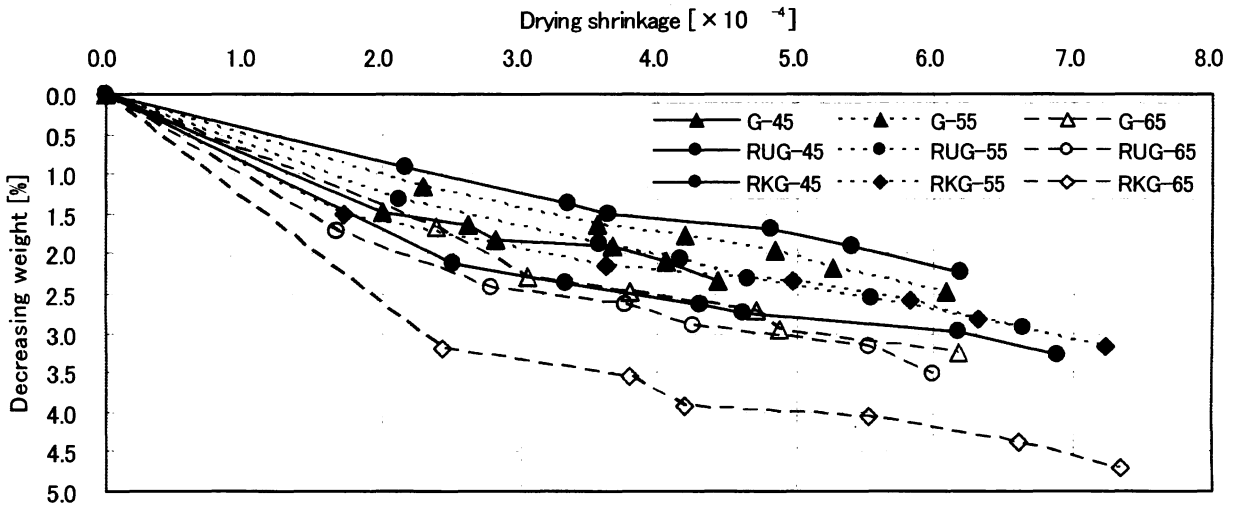

Fig.8 Drying shrinkage and decreasing weight

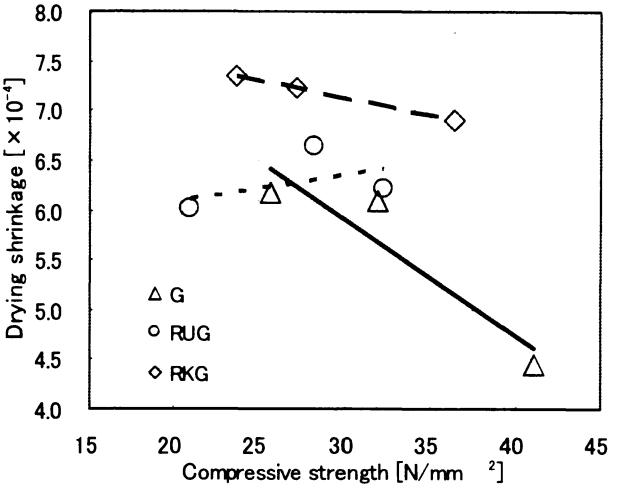

Fig.9 Compressive strength and drying shrinkage

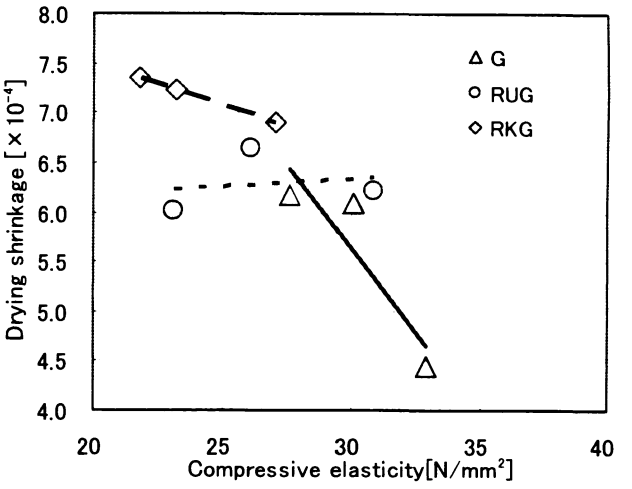

Fig.10 Compressive elasticity and drying shrinkage

5.3 Neutralization

Fig.11 shows the experimental result of accelerated carbonation tests for concrete using 10cm×10cm×40cm rectangular specimen under the condition of 20℃, 60% RH and 5% CO_2 gas density. The neutralization is accelerated corresponding to water-cement ratio, and it seems that the neutralization of normal concrete makes slower than recycled concrete. The reason of that is following. Concerning on recycle concrete, drying shrinkage and decreasing weight are larger than normal concrete, i.e. emission of much water then the water content ratio on the surface decrease. Consequently neutralization of recycled concrete accelerates rapidly under the dry surface.

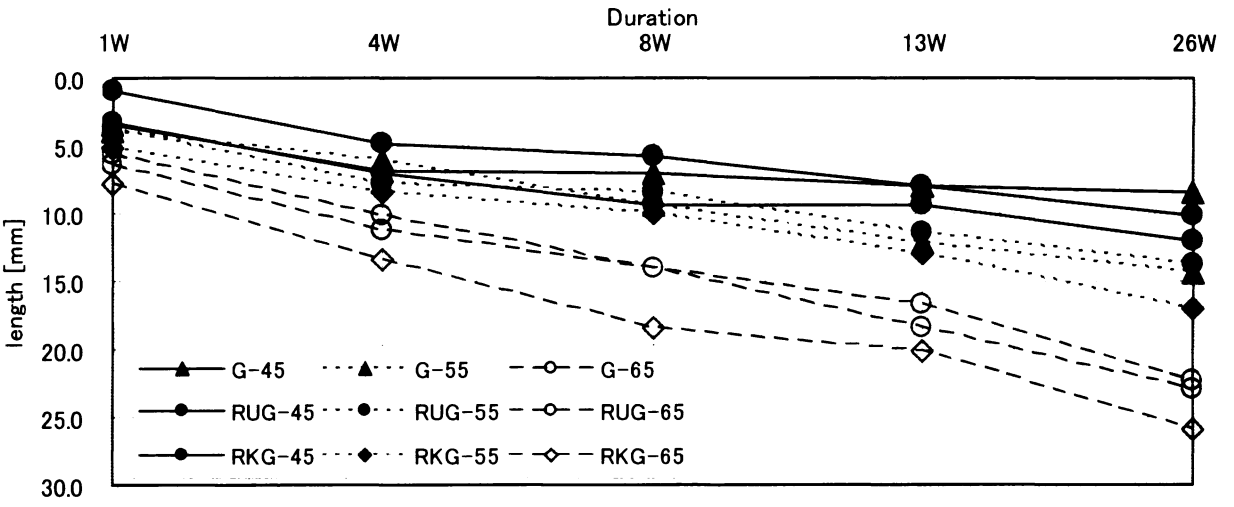

Fig.11 Length of neutralization

6. Conclusions

Some experiments on the properties of fresh and hardened concrete by using two kinds of high quality recycled coarse aggregates were carried out and the results were compared with the characteristics of normal concrete. Both of high quality recycled coarse aggregates were not inferior to virgin material. And synthesizing all

experimental results, it is considered that high quality recycled coarse aggregates are able to apply for real structure under the condition of well mixed proportions.

Acknowledgement

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References

1) Japanese Architectural Standard Specification JASS 5 Reinforced Concrete Work 2003
2) M.Kikuchi, Y.Dousyou, A.Yasunaga, K.Ehara and A.Masuda: Influence of quality of recycled aggregate on quality of recycled aggregate concrete, J.Structural and Construction Engineering, Architectural Institute of Japan, No.474, pp.11-20, Aug, 1995.
3) Y.Dousyou, M.Kikuchi, A.Masuda and A.Koyama: Influence of properties of original concrete on qualities of recycled aggregate concrete, J.Structural and Construction Engineering, Architectural Institute of Japan, No.485, pp.1-10, July, 1996.
4) T.Kiuchi: A study on the recycle concrete by using type Ⅲ recycled coarse aggregate, Memoirs of the Faculty of Engineering Osaka City University, Vol.42, Dec, 2001.
5) H.Kasami, K.Shimizu and Y.Kudoh: Experimental study on the effect of adhered cement mortar on the properties of recycled aggregate part3 effect of adhered cement mortar on the density and absorption of recycled aggregate, Summaries of Technical Papers of Annual Meeting Architectural Institute of Japan, A-1, Materials and Construction, pp.689-690, Sep, 1998.